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<p>During the project we put together and developed a titanium:sapphire mode-locked laser. The output of the laser was characterized as optical pulses between 100 to 200 femtoseconds in duration. The laser was tunable between 900 nanometers and 1000 nanometers. This tuning range is ideal for studies on indium phosphide. The laser could also be operated in the continuous wave mode.</p> <p>In addition to building and characterizing the laser we used the laser to carry out an investigation of the photorefractive behavior of indium phosphide. In particular, we characterized the two wave mixing gain. We found the gain to display an intensity dependent resonance. That is, as predicted by theory, we found the gain to peak at a given intensity. Also, as predicted by theory, we found the relative phase between the intensity spatial pattern and the space-charge field spatial pattern to depend on the intensity. In particular, our measurements demonstrated, for the first time, that the relative phase was 0 degrees for low intensities, that it was 90 degrees at intensity for which the gain peaked and that it was near 180 degrees for high intensities.</p> <p>As a result of our work it is clear that the photorefractive model for indium phosphide is accurate and that it can be used to determine the sign of the photocarrier, drift length, diffusion length, mobility, and dopant concentration.</p>		
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FINAL TECHNICAL REPORT

**TITLE: FEMTOSECOND TRANSPORT AND SPACE-CHARGE FIELD
FORMATION IN SEMICONDUCTORS USING THE
PHOTOREFRACTIVE EFFECT**

Award No. F49620 -92-J0452DEF

OBJECTIVE

The object of the research was to develop a Ti-Sapphire laser which would then be used to investigate the photorefractive properties of InP grown at Hanscom Air Force Base.

RESEARCH RESULTS

During the project we developed a physical understanding and demonstrated some of the unusual aspects of photorefraction in InP.

At the start of the project we developed a cw-node-locked Ti-Sapphire laser which was tunable in the 900 nanometer to 1000 nanometer range. We used the Ti-Sapphire laser to examine two-wave mixing in InP using both the c.w. operation and the mode-locked operation of the laser. We found, as predicted, that the two-wave coupling gain displayed an intensity dependent resonance. This resonance was independent of whether the laser was operated in the c.w. mode or in the femtosecond mode. The peak in gain depended only on the average intensity.

In addition to the intensity dependent gain we also investigated the relative phase between the intensity spatial pattern and the index spatial pattern. We observed the phase to vary from 0 degrees below the resonant intensity, to react 90 degrees at the resonant intensity, and to move to 180 degrees above the resonant intensity.

Different techniques can be used to measure the phase shift between the intensity pattern and the index pattern. In the method used here, the phase shift is determined experimentally by measuring the gain and the diffraction efficiency in a TWM experiment.

For our experiment the grating vector was oriented along <001> and the optical beams propagated along <110> and were polarized along <100> (figure 1)

The TWM gain Γ is proportional to the imaginary part of the space charge fields:

$$\Gamma = \delta \frac{\text{Im}(E_1(z))}{m(z)} ; \quad \text{with } \delta = \frac{2\pi n_0^3 r_{41}}{\lambda_0 \cos(\theta)} \quad (1)$$

Where n_0 is the refractive index, r_{41} is the electro-optic coefficient and θ is the Bragg angle inside the crystal.

A grating index created by TWM inside a crystal with a length L has a diffraction efficiency given by:

$$\eta = \sin^2 \int_0^L \frac{\delta}{4} \sqrt{\text{Im}(E_1(z)^2) + \text{Re}(E_1(z)^2)} dz \quad (2)$$

Therefore the relative phase shift ϕ can be calculated from:

$$\sin(\varphi) = \frac{\text{Im}(E_1(z))}{\sqrt{\text{Im}(E_1(z))^2 + \text{Re}(E_1(z))^2}} = \frac{\Gamma \int_0^L m(z) dz}{4 \text{Arc sin}(\sqrt{\eta})} \quad (3)$$

$$\text{with } \int_0^L m(z) dz = \frac{4 \arctan(\sqrt{\beta}) - 4 \arctan\left(\sqrt{\frac{\beta}{\exp(\Gamma L)}}\right)}{\Gamma} \quad (4)$$

Where β is the pump to signal ratio at the entrance face.

Experimentally, the gain Γ is found from the TWM signal amplification. To measure the diffraction efficiency η , the diffracted part of the pump in the signal direction is measured during the TWM experiment by switching off the signal beam. The decay time for the photorefractive index grating with only the pump beam on is around 50 ms for an intensity of 100 mW/cm². Therefore, a shutter speed of 500 μ s was used to switch off the signal beam while a digital oscilloscope acquired the diffracted signal from the pump beam.

To limit the intensity variation and consequently the phase variation along the crystal due to absorption, a thin 1.7 mm long crystal was used in the experiment. In this case, we can assume that the phase shift was constant throughout the sample. The temperature of the sample was stabilized to 273 K with peltier coolers and a 12 kV/cm d.c. electric field was applied in the <100> direction. The measurement was taken using 1.02 μm wavelength light from a Tunable Ti-Sapphire laser. The results of the relative phase and the gain as a function of total intensity are shown in figure 2. The sample exhibits a sharp resonance with a maximum gain greater than 10 cm^{-1} . As predicted the phase shift varies from 0 to near 180 degrees as a function of intensity and reaches a value of 90 degrees at the resonance intensity. Since the measurement determines only $\sin(\phi)$, it is not possible to differentiate a phase angle of α from a phase angle of $(180-\alpha)$. To fit the experimental points numerous parameters such as $n_{T0}, P_{T0}, \sigma_p^\circ$ and σ_n° are needed but good qualitative agreement is found between the theoretical curve of figure 3 and the measurements of figure 2.

In conclusion, we have demonstrated experimentally that the phase shift between the index grating and the illumination grating for TWM experiments in InP:Fe with a d.c. applied field is strongly intensity dependent. The phase shift is 0 degree for low intensity, then increases to 90 degrees at the resonance intensity and reaches 180 degrees for high intensity. This result gives further credibility to the Picoli model. We are submitting these results to Optics Letters for publication.





